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Giovanni Vezzoli, Bruno Lombardo & Franco Rolfo

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Petrology of the Tista and Rangit river sands (Sikkim, India)

Giovanni Vezzoli [(1)], Bruno Lombardo [(2,†)] and Franco Rolfo [(2,3)].

[(1)] Dipartimento di Scienze dell'Ambiente, del Territorio e di Scienze della Terra , Piazza della Scienza 4, I-20126 Milano (Italy).

[(2,†)] CNR, Istituto di Geoscienze e Georisorse, Sezione di Torino. Via Valperga Caluso 35, I-10125 Torino, (Italy)

[(3)] Dipartimento di Scienze della Terra, Via Valperga Caluso 35, I-10125 Torino, (Italy)

Abstract

The Tista River originates from glaciers in the North Sikkim (India) and flows towards southwest draining most of the Himalaya tectonic units up to Triveni locality, where it is joined by the Rangit River (its larger tributary). Tista fluvial profile has moderate concavity ($\theta = 0.39$) and high steepness indices ($k_{sn} = 380$). In Sikkim, Tista sand is characterized by quartz, feldspars and high-rank metamorphic rock fragments from the Higher Himalayan Crystallines. After Triveni, Tista River leaves Sikkim and enters in the Indian (West Bengal) and in Bangladesh floodplain to meets the Brahmaputra River after ~ 400 km from its source. In the alluvial plain, Tista carries sand rich in quartz, feldspars and low-rank metamorphic lithic grains. The Rangit River sourced from a glacier of Mt. Kabru in the southern Kangchendzonga region (West Sikkim). Its fluvial profile display high concavity ($\theta = 0.75$) and high steepness indices ($k_{sn} = 408$). Rangit sand from the upper catchment (Chokhurang Chu and Prek Chu) includes quartz, feldspars, and biotite. Fluvial detritus from the metacarbonates of the Pandim Massif includes high-grade metamorphic lithic grains, diopsidic pyroxene and amphiboles. Sand from the Higher Himalaya Crystallines (Kalej and Ramam Khola) is characterized by high-grade gneissic rock fragments. Before the confluence with the Tista River at Triveni, Rangit sand is enriched in low rank metamorphic grains deriving from the Daling successions of the Lesser Himalaya. Quantitative provenance analysis (integrated bulk-sand petrography, statistical analysis and river-profile analysis) indicates that the Rangit River in Sikkim contributes ~ 60% to the total Tista sand flux in Bangladesh.

1. Introduction

The high-relief and tectonically active Himalayan range, characterized by markedly varying climate but relatively homogeneous geology along strike, is a unique natural laboratory in which to investigate several factors controlling the composition of orogenic sediments (Najman et al., 2008). The Himalayan belt, characterized by extreme elevation and relief, is subject to intense erosion and represents the most important single source of terrigenous sediments on Earth (e.g. Milliman and

Meade, 1983). The huge mass of sediments produced exceeds by far the storage capacity of the associated foreland basin, and after long-distance fluvial to turbiditic transport accumulates in huge submarine fans over Indian Ocean crust (France-Lanord et al., 1993; Goodbred and Kuehl, 2000; Clift et al., 2001). In this article we present high-resolution petrographical data on modern sands and fluvial profile analysis from the Tista and Rangit rivers in Sikkim and petrographical data from the Tista sand in Bangladesh, in order to evaluate similarity among them. Mathematical similarity was quantified by the Aitchison's (1986) distance and the relative contribution of the mountain tracks of the Tista and Rangit river sands in Sikkim to the total Tista sand flux in Bangladesh was calculated by forward end-member modelling (Weltje, 1997). Such quantitative information obtained from actualistic studies (Ingersoll, 1990) represents an effective additional tool to trace fluvial processes both in space and time (Vezzoli et al., 2013; Garzanti et al., 2011) and is crucial to interpret the tectonic and erosional evolution of orogenic belts from ancient sedimentary successions preserved in foreland to remnant ocean basins (Najman et al., 2009).

2. Drainage Basin

The Tista River (one of the main Himalayan tributaries of the Brahmaputra River) rises at ~ 5280 m a.s.l. from the glaciers in the North Sikkim (India; Fig. 1) and flows ~ 150 km in southwest direction up to Triveni where it is joined by Rangit River (its larger tributary) which drains West Sikkim district (Fig 2). From Triveni downstream, the Tista River leaves the Sikkim state and enters in the floodplain of West Bengal (India) and Bangladesh to join the Brahmaputra River after ~ 400 km from its source (Fig. 1). Tista watershed in Sikkim is ~ 6900 km^2 and is fed by the melting snow of the Himalayas in early summer and by the monsoon rains in July to September (mean annual precipitation 3539 mm in the capital city of Gangtok). More than 60% of the drainage basin lies above 3,000 m and it is characterised by steep to very steep slopes (altitudes varies from the 8586 m of Mt. Kangchendzonga to 215 m a.s.l. of Triveni locality within aerial distance of ~ 90 km; Centre For Inter-Disciplinary Studies Of Mountain & Hill Environment, 2014). The Rangit River (length ~ 80 km, catchment area ~ 2200 km^2) sourced from a glacier of Mount Kabru (7412 m a.s.l.) at the southern flank of the Kangchendzonga Massif (8586 m a.s.l, Fig. 2). About 40% of the Rangit watershed is covered by mountains ≥ 3000 m, the mean annual precipitation is ~ 3,000 mm and its major tributaries are the Prek Chu, Chokhurang Chu, Kalej Khola and Ramam Khola (Fig. 2; Centre For Inter-Disciplinary Studies Of Mountain & Hill Environment, 2014). The Tista catchment in Sikkim is subjected to intense landslide activities. Landslides covered and area ≥ 1% of the total basin and ≥ 0.5% in the Rangit watershed and supply, mainly in form of debris flows, great amounts of sediments into the Tista and Rangit river channels (~ $4*10^6$ ton/a; Centre For Inter-Disciplinary Studies Of Mountain & Hill Environment, 2014).

3. Geological setting

Mt. Kangchendzonga is the third-highest and easternmost eight-thousander and sits in a broad synform of regional extent west of the Rangit tectonic window (Fig. 2). This tectonic window cuts deeply through the Himalayan nappe pile, exposing the Daling schists of the Lesser Himalayan Sequence (LHS). Structurally below, the Damudas are a non-metamorphic sequence of Permo-Carboniferous sedimentary rocks of Gondwana affinity (Gansser, 1964). At the northern end of the Rangit tectonic window, structurally upwards from south to north, metamorphic grade increases rapidly from greenschist-facies in the uppermost Daling schists (biotite gneiss) up to amphibolite-facies in the Main Central Thrust Zone (MCTZ) and finally to Grt-Ky-Sil-Bt migmatites with Grt-bearing leucosomes of the Darjeeling Gneiss between Yuksom and Bakhim (Harris et al. 2004). The upper Rathong Chu and Prek Chu valleys are carved in a large body of granitic to granodioritic orthogneiss with intercalations of biotite paragneiss and rare bodies of amphibolites belonging to the Higher Himalayan Crystallines (HHC). Leucogranite sheets first occur south of Bakhim (Harris et al. 2004) and are increasingly abundant in the south face of Rathong and Kabru Dome (Searle and Szulc 2005) and south of Guicha La in the north ridge of Mt. Pandim (6,691 m). In the south-west face of this peak a layered sequence of calc-silicate rocks and marbles is conspicuous and was noted long ago by Hooker (1854) and Garwood (1903). The layered sequence is associated with biotite schists with quartz-sillimanite nodules and is cut by leucogranite dykes. Leucogranite is homogeneous and in places displays the star-shaped tourmaline clusters typical of Miocene leucogranites throughout the Himalayas. The lithological association of Mt. Pandim is very similar to the banded calc-silicate rocks and marbles occurring in the Mt. Everest region above the Lhotse Shear Zone at the base of the greenschist-facies North Col Formation, the lowest member of the Tibetan Sedimentary Sequence (TSS – see for instance Lombardo et al., 1993). The geological setting of Pandim is also reminiscent of that described by Gansser (1983) in west Bhutan, where a folded shear zone places the low-grade Cheka phyllites and calc-silicate rocks above high-grade gneisses and migmatites of the HHC. Additional details about the geologic setting of Mt. Kangchendzonga can be found in Rolfo et al. (2006) and Mosca et al. (2011, 2012).

4. Methods

4.1 Sampling and analytical procedures

Tista bed-load sands were sampled on active bars in Bangladesh and in Sikkim from 1999 to 2002. In the autumn 2004, 10 sand-size samples were collected from active fluvial bars in the West

Sikkim district (Fig. 1, 2). Samples were impregnated with Araldite, cut into standard thin sections, stained with alizarine red to distinguish dolomite and calcite, and analysed by counting 400 points under the microscope (*Gazzi-Dickinson method*; Ingersoll et al., 1984). Sands were classified according to their main components (Q = quartz; F = feldspars; L = lithic fragments) and full quantitative information was collected on coarse-grained rock fragments. In particular, metamorphic types were classified according to protolith composition and metamorphic rank. Average rank of rock fragments in each sample was expressed by the Metamorphic Indices MI and MI*. MI varies from zero (in detritus shed by exclusively sedimentary and volcanic cover rocks) to 500 (in very-high-rank detritus shed by exclusively high-grade basement rocks), whereas MI* considers only metamorphic rock fragments and thus varies from 100 (in very-low-rank detritus shed by exclusively very low-grade metamorphic rocks) to 500 (Garzanti and Vezzoli, 2003). The petrographic and heavy-mineral parameters are provided in Table 1.

4.2 River-profile analysis

Drainage patterns in orogenic belts are influenced by tectonic strain, and river profiles may reorganize dynamically in response to changes in the stress regime. Landscape topography and bedrock-channel network can thus reveal much about the evolution of tectonically active landscapes (e.g. Castelltort et al., 2012; Kirby and Whipple, 2012). Streams, however, may also be passive features (Castelltort and Simpson, 2006), and record long-term continental convergence and collision (Hallet and Molnar, 2001) or past reorganization events driven by surface uplift (Clark et al., 2004). Close relationships between river drainages and exhumation of deep structural levels within erosional windows and half-windows are observed all along the Himalayan arc, but the most spectacular examples occur at the eastern and western syntaxial terminations of the belt (Garzanti et al., 2004; 2005). Fluvial profiles are well-described by a power-law relationship between the local channel gradient S and the contributing drainage area A (a proxy for discharge), in the form (Flint 1974) $S = k_s A^{-\theta}$ where θ (referred to as the concavity index) describes the rate of change of channel gradient with drainage area, and k_s is a measure of bedrock-channel response to differential rock uplift if other controls such as rock type, climate, flood hydrology or sediment flux are negligible or sufficiently constrained (Whipple and Tucker, 1999; Kirby et al., 2003; Vezzoli et al., 2014). Here we use the normalized steepness index (k_{sn}), corrected for the influence of basin area and channel concavity by a fixed reference concavity of 0.45 for all river segments (Schlunegger et al., 2011; Norton and Schlunegger, 2011). For the Tista catchment in Sikkim, we performed stream-profile analysis (Fig. 4) by evaluating stream gradient and its deviation from ideal equilibrium using TecDEM (software shell implemented in MATLAB©; Shahzad and Gloaguen, 2011) from a 30 m resolution digital elevation model provided by ASTER GDEM (http://gdem.ersdac.jspacesystems.or.jp)

4.3 Statistics.

Detrital modes obtained with petrographic and mineralogical analyses are nonnegative and invariably sum up to a constant (i.e., 1 or 100%). Such a constant-sum constraint implies that variables neither vary independently from each other nor follow a multivariate normal distribution and therefore fail major prerequisites of standard statistical methods (Aitchison 1986). A family of log-ratio transformations from the simplex to the Euclidean space were thus introduced to perform statistical techniques such as principal component analysis (Buccianti et al. 2006). In order to discriminate homogeneous provenance groups within our data set, we applied centered log-ratio (clr) transformations (Aitchison and Grenache 2002). We used the compositional biplot (Gabriel 1971) for graphical display of both multivariate observations (points) and variables (rays; Fig. 5). The problem of zero values was solved by the thin our data set, we applied centered Martin Fernandez et al., 2003). As input value for zero replacement we chose 0.001, which is less than half the value corresponding to 1 out of 400 counted grains. Next, in order to quantify the mathematical similarity and the relative contribution from the mountain tracks of the Rangit and Tista river sands in Sikkim to the Tista River sand in Bangladesh, the Aitchison's distance (d^2) and the forward end-member modelling of integrated bulk-petrography data was calculated (Weltje, 1997; Aitchison et al., 2000; Garzanti et al., 2012).The statistical analysis of petrographic and mineralogical datasets was performed by using CoDaPack (Comas-Cufí and Thió-Henestrosa, 2011).

5. Results

5.1 Sediment Provenance

Tista River sand in Sikkim (sample Tr) is characterized by quartz, plagioclase and K-feldspar. Rock fragments include mainly high-rank metamorphic grains from the Higher Himalayan Crystallines (MI* 424, MI 424) whereas heavy mineral suite includes amphiboles, sillimanite, kyanite and garnet. In the upper course of the Rangit drainage basin, the Prek Chu (sample A) and Chokhurang Chu (sample C) flow across large bodies of granitic to granodioritic orthogneiss with intercalations of biotite paragneiss and minor bodies of amphibolite. These rivers carry feldspar-rich sands with granitoid rock fragments, monocrystalline quartz, microcline to perthitic alkali feldspars, twinned and sericitized plagioclase. Biotite is common). Sand from Mt. Pandim (sample B) includes abundant metacarbonate lithic grains, granitoid and gneissic rock fragments (MI* 414, MI 414). Plagioclase, largely sericitized, prevails over K-feldspar. Heavy minerals include diopsidic pyroxene and minor amphibole. The Rathong Chu flows across Grt-Ky-Sil-Bt migmatites with Grt-bearing leucosomes of the Darjeeling Gneiss, between Bakhim and Yuksom (samples D and E). The Rathong River carries litho-feldspatho-quartzose sand with a rich plagioclase suite. Granitoid and gneissic lithic grains with biotite are common (MI* 443, MI 443). The Kalej and Ramam Khola (samples G and I) rise upstream up to the high-grade metamorphic units of the Main Central Thrust Zone. Their sands are characterized by monocrystalline quartz, feldspars (alkali feldspars, twinned and sericitized plagioclase), metasandstone, gneissic and granitoid lithic grains (MI* 413, MI 413). Heavy minerals include amphibole, sillimanite, epidote, garnet and biotite. In the middle part of the watershed (sample F), Rangit sand is feldspatho-litho-quartzose with plagioclase largely sericitized and minor K-feldspar. Rock fragments are mainly low-rank metasandstone grains from the Lesser Himalayan units and minor granitoid grains (MI* 362, MI 362). Heavy minerals include garnet, biotite and minor muscovite. Rangit sand composition changes to litho-feldspatho-quartzose downstream (sample H and I), where high-grade metamorphic lithic grains increase (MI* 423, MI 423), reflecting contributions from the metamorphic units drained by the Kalej Khola and Ramam Khola. The heavy-mineral suite becomes moderately rich and garnet-dominated, with amphiboles, sillimanite and kyanite. Finally, Rangit sand is enriched in low rank metamorphic lithic grains deriving from the Gondwanian successions of the Lesser Himalaya (sample L). River sand composition includes slate, metasandstone and quartz-mica lithic grains (MI* 357, MI 353). Heavy-mineral suites are characterized by garnet, amphiboles, sillimanite and pyroxenes. Tista River in Bangladesh (sample Ti) carries sand rich in quartz, feldspars and low-rank metamorphic lithic grains (MI* 372, MI 364). Heavy-mineral suite includes amphiboles, garnet and sillimanite. Ternary diagrams of petrographic and mineralogical signatures of sands from the Tista catchment (Fig. 3) display good similarity between composition of Rangit sand in Sikkim and Tista sand in Bangladesh (samples L and Ti).

5.2 River Morphometry

The Rangit River has high concavity (θ = 0.75) and high-gradient channel (k_{sn} = 408), whereas Tista River in Sikkim has low concavity (θ = 0.39) and minor steepness index (k_{sn} = 380; Fig. 4). Following Whipple (2004), high concavities (0.7 - 1.0) are associated with the downstream decrease in rock-uplift rate and/or rock strength (e.g. a downstream transition to fully alluvial conditions and disequilibrium conditions results from a temporal decline in rock-uplift rate) whereas low concavities (< 0.4) are associated either with short steep drainage influenced by debris flows, or with downstream increase in incision rate or rock strength, commonly related to knickpoints.). Steepness indices essentially integrate seismic activity and rock deformation over geological timescales, and higher values have been related to higher erosion and/or exhumation rates (Ouimet et al., 2009; Cyr et al., 2010). Our results may thus suggest high erosion rates in the drainage basin and in particular in the Rangit catchment. The Sikkim Himalaya, with its rugged topography, ongoing seismic activity and heavy rainfall, is subjected to intense landslide activities and, in particular, in the Rangit catchment the development rate of new landslides is very high. As an example, on 18th September 2011 a magnitude Mw 6.9 earthquake, close to the Mt. Kangchendzonga, has triggered more than 1100 new landslides (Bhasin et al., 2002; Centre For Inter-Disciplinary Studies Of Mountain & Hill Environment, 2014; Martha et al, 2014).

5.3 Statistical analysis

Compositional biplot (Fig. 5) show as the first two principal components, used for the approximation of the transformed observations on the plane, explain 56% of variability of the clr-transformed data. Thus, the structure of the compositions is already quite clearly visible. Samples from the Prek Chu and Chokhurang Chu are displayed in the lower right corner of the plot and are characterized by quartz and feldspars. Sample from Mt. Pandim includes abundant metacarbonate lithic grains whereas the positions of Rathong Chu points demonstrate different properties, reflecting the privileged position of biotite in this group. The positions of Rangit samples, in the upper right corner and in the central left of the biplot, testify the evolution of the sediment composition from the high-grade metamorphic grains, shed by the Higher Himalaya crystalline units, to the low-rank metamorphic grains deriving from the Daling Group of the Lesser Himalaya. Moreover, compositional biplot show as the distance between composition of Rangit sand in Sikkim and Tista sand in Bangladesh is minimum (samples L and Ti; Aitchison's distance $d^2 = 61$). Instead, more distance and therefore minor similarity ($d^2 = 134$) is between Tista sand in Sikkim and Tista sand in Bangladesh (samples Tr and Ti). Forward end-member modelling of integrated bulk-petrography data indicates that the relative contributes of the Rangit River sand in Sikkim to the Tista sand flux in Bangladesh is ~ 60% and the relative contribution of the Tista River sand in Sikkim to the Tista sand flux in Bangladesh is ~ 40%. Thus, calculations based on petrographic data and river profile on the same sample set suggest that the Rangit catchment, representing only ~ 17% of the total Tista basin area (12540 km^2), may be considered the major contributor of total sand reaching the Brahmaputra River.

6. Conclusion

This study emphasizes the importance of the mountainous rivers on the control of sediment yield in the drainage basins. Tista sand in Sikkim is characterized by quartz, feldspars and high-rank metamorphic grains from the Higher Himalayan Crystallines. Rangit sand deriving from the Kangchendzonga Massif are quartzofeldspathic with biotite and sillimanite. Sand from the metacarbonates of the Pandim Massif includes diopside. Fluvial sediment deriving from the successions of the Lesser Himalaya is quartzolithic with abundant low rank metamorphic rock fragments. Tista River in Bangladesh carries sand rich in quartz, feldspars and low rank metamorphic lithic grains. Petrographic analysis thus indicates the good similarity between the Rangit sand in Sikkim and Tista sand in Bangladesh. Rangit fluvial profile has high concavity and high-gradient channel, suggesting high erosion rate in the watershed. This result is also confirmed by the intense landslide activities widespread in the Rangit catchment. The Aitchison's distance between the signatures of Rangit sand in Sikkim and Tista sand in Bangladesh is minimum (d^2 = 61). Forward end-member modeling identifies the Rangit River as major contributor (~ 60%) to the total Tista sand flux in Bangladesh.

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Captions figures and table

Figure 1. Geographic map of the study area indicating the Tista sample location in Bangladesh (Ti). Yellow triangle - Mt. Kangchendzonga (8586 m a.s.l)

Figure 2. Topographic characteristics of the Tista drainage basin in Sikkim, showing the Rangit watershed and the location of sand-size samples. Dotted lines separate the main tectonic units (after Rolfo et al., in press). LHS = Lesser Himalayan Sequence; MCTZ = Main Central Thrust Zone; HHC = Higher Himalayan Crystallines; TSS = Tibetan Sedimentary Sequence. Inset: schematic tectonic map of the Himalayan chain. MCT = Main Central Thrust.

Figure 3. Framework petrography in modern sands of the Tista and Rangit rivers. Ternary diagrams; Q = quartz, F = feldspar and L = aphanitic lithic fragments; Granitoid, R_{123} (unmetamorphosed to medium rank metamorphic lithic grains) and R_{45} = high to very high metamorphic lithic grains (Garzanti and Vezzoli, 2003). The southern reaches of the Kangchendzonga Massif shed high-rank quartzo-feldspathic detritus with granitoid rock fragments

and biotite (Prek Chu, A). Pandim River (B) draining calcsilicate fels and marbles of Mt. Pandim carry abundant metacarbonate lithic grains with diopsidic pyroxene and amphibole. The Ramam Khola (I), right-bank Rangit tributary, carries high-rank gneissic rock fragments with biotite and sillimanite. Lower reaches of the Rangit River (L) include schists to quartz-mica lithic grains from lower-grade Lesser Himalayan metasediments exposed in the Rangit Tectonic Window. Fluvial detritus from Tista in Sikkim (sample Tr) is characterized by quartz, plagioclase and K-feldspar. Rock fragments include mainly high-rank metamorphic grains from the Higher Himalayan Crystallines. The heavy mineral suite includes amphiboles, sillimanite, kyanite and garnet. Tista River in Bangladesh (sample Ti) carries sand rich in quartz, feldspars and low-rank metamorphic lithic grains. The heavy-mineral suite includes amphiboles, garnet and sillimanite. The ternary diagrams display the good similarity between samples of the Rangit and Tista River in Bangladesh (samples L, Ti). Q = quartz, K = K-feldspar, P = plagioclase; b = biotite; s = sillimanite; p = pyroxene; a = amphibole; Gr = granitoid grains; Gn = gneissic grains; C = metacarbonate grains; Lms = lower-grade metasedimentary grains. Photographs with crossed polars; yellow bar = 250 μm.

Figure 4. Area, longitudinal river profile, concavity index (θ) and normalized steepness index (k_{sn}) for the Tista and Rangit rivers in Sikkim.

Figure 5. Compositional biplot of modern sands of the Tista and Rangit rivers discriminated different provenance groups within data set. Graph show the minimum distance between petrographic signature of the Rangit sand in Sikkim (sample L) and the composition of the Tista sand in Bangladesh (sample Ti). The first and second principal components account for 56% of total variance.

Table 1. Petrographic and heavy-mineral detrital modes for modern sands from the Tista and Rangit rivers. Q = quartz; K = K-feldspar; P = plagioclase; Lv = Volcanic and subvolcanic lithic fragments; Lc = Carbonate lithic fragments; Ls = Terrigenous lithic fragments (shale, siltstone); Lm = metamorphic lithic fragments; Lu = Ultramafic lithic fragments; Mu = muscovite; Bt = Biotite; A/P = amphiboles - pyroxene; &HM = other heavy minerals (e.g. sillimanite, epidote); MI and MI* = Metamorphic Indices reflecting average metamorphic grade of source rock (Garzanti and Vezzoli, 2003).

Figure 1. Vezzoli et al

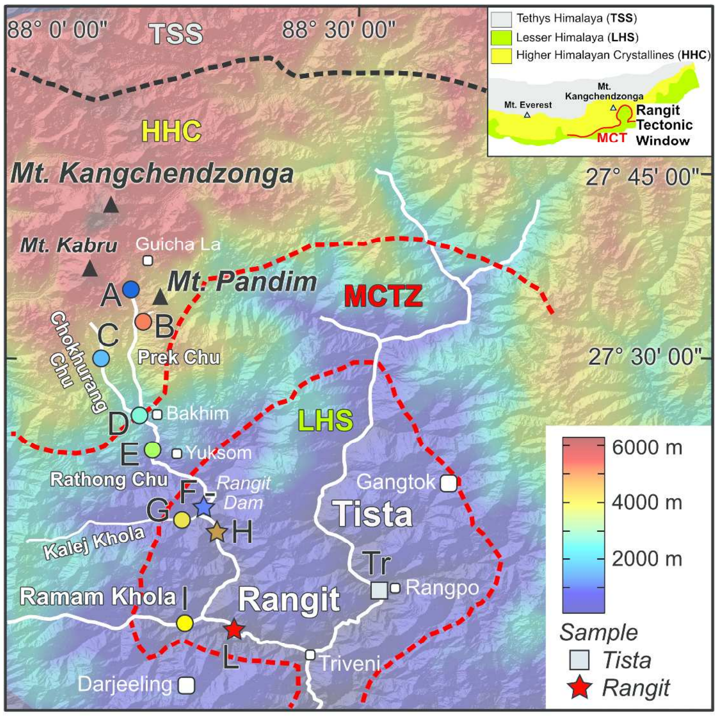

Figure 2 Vezzoli et al

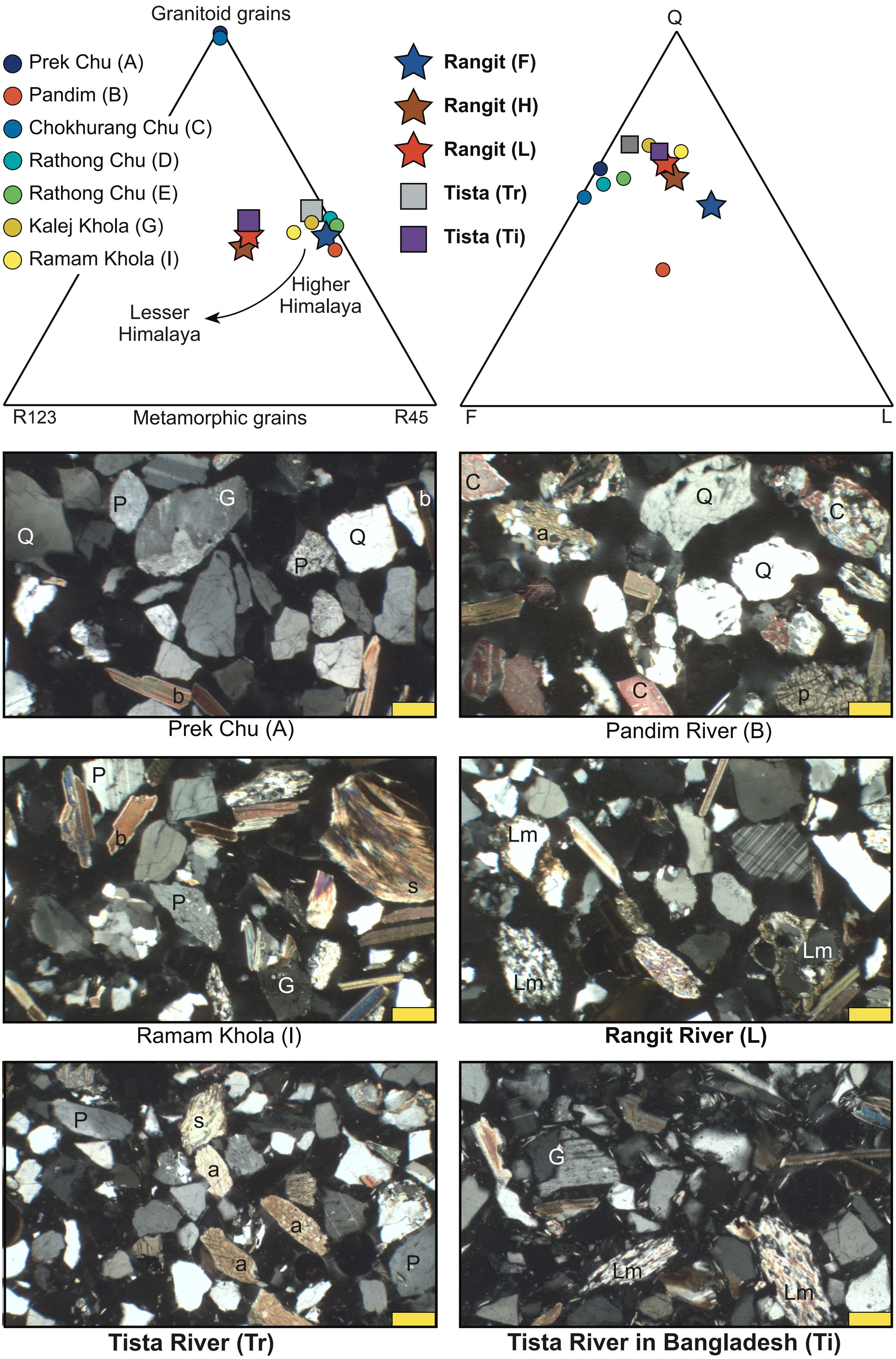

Figure 3 Vezzoli et al

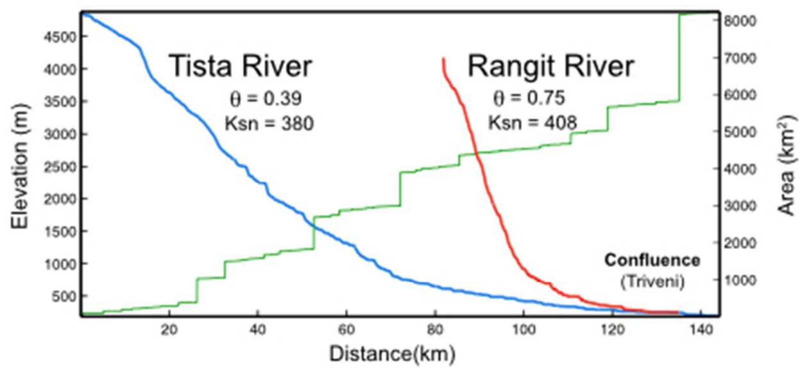

Fig. 4 Vezzoli et al

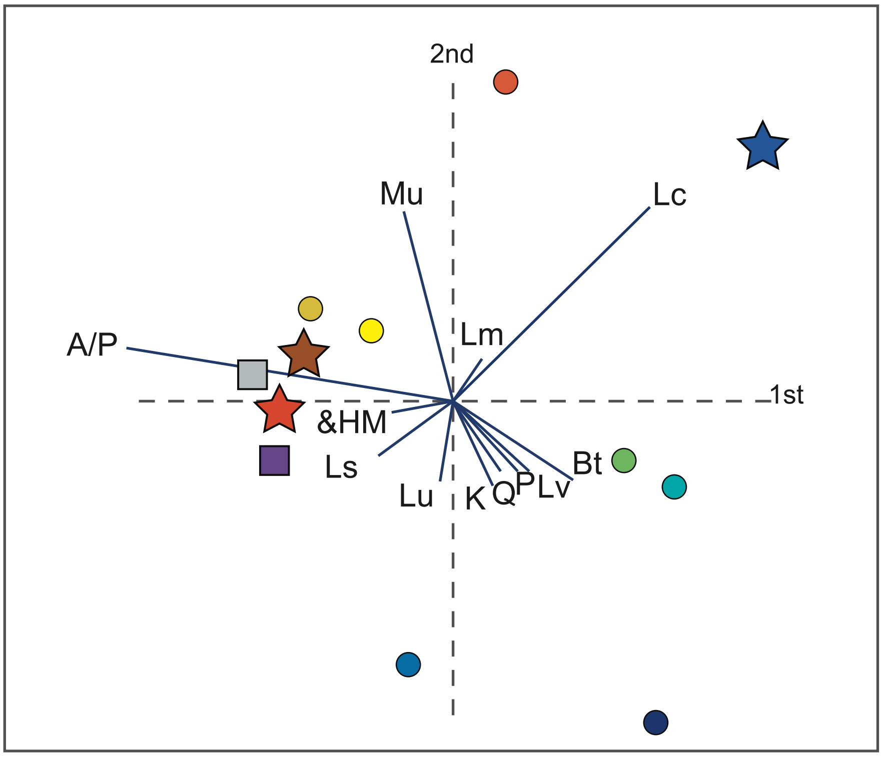

Figure 5. Vezzoli et al

River	Coordinates	sample	Q	K	P	Lv	Lc	Ls	Lm	Lu	Mu	Bi	A/P	&HM	total	MI*	MI
Sikkim (India)																	
Prek Chu	27°33'36.13"N; 88°10'59.92"E	A	58.8	16.3	18.0	0.0	0.0	0.0	0.69	0.0	0.0	5.9	0.0	0.3	100.0	n.d.	n.d.
Pandim	27°33'32.17"N; 88°11'34.95"E	B	31.5	11.9	19.9	0.0	8.4	0.0	17.5	0.0	0.5	4.4	5.2	0.7	100.0	414	414
Chokhurang Chu	27°32'58.64"N; 88° 7'56.38"E	C	54.0	21.6	20.9	0.0	0.0	0.0	0.3	0.0	0.0	2.1	0.3	0.7	100.0	n.d.	n.d.
Rathong Chu	27°25'15.25"N; 88°11'21.75"E	D	47.3	9.5	19.8	0.0	0.0	0.0	2.5	0.0	0.4	20.5	0.0	0.0	100.0	438	438
Rathong Chu	27°22'46.15"N; 88°12'51.08"E	E	52.1	11.8	16.1	0.0	0.0	0.0	5.7	0.0	1.3	12.7	0.0	0.4	100.0	448	448
Rangit	27°16'51.06"N; 88°16'35.12"E	F	43.0	3.8	8.4	0.0	1.0	0.0	24.1	0.0	4.4	13.5	0.0	1.7	100.0	362	362
Kalej Khola	27°16'20.75"N; 88°16'7.41"E	G	53.3	6.0	10.9	0.0	0.0	0.0	6.7	0.0	9.1	10.9	2.8	0.4	100.0	414	414
Rangit	27°15'30.54"N; 88°18'1.11"E	H	55.2	5.3	11.9	0.0	0.0	0.0	13.2	0.0	1.6	4.1	2.5	6.3	100.0	423	423
Ramam Khola	27° 7'44.56"N; 88°16'6.33"E	I	53.3	5.6	6.2	0.0	0.0	0.0	13.4	0.0	5.5	14.8	0.3	0.9	100.0	412	412
Rangit	27° 6'25.00"N; 88°19'44.62"E	L	53.4	7.8	9.3	0.0	0.0	0.3	16.1	0.0	2.6	7.9	1.6	0.9	100.0	357	353
Tista (Rangpo)	27° 10'33.00"N; 88°31'13.00"E	Tr	56.9	10.1	11.1	0.0	0.0	0.0	3.4	0.5	1.5	4.5	5.0	7.0	100.0	424	424
Bangladesh																	
Tista River	25°47'30.05"N; 89°26'19.36"E	Ti	50.0	8.3	6.5	0.0	0.0	0.3	8.5	0.0	7.8	14.7	3.0	1.0	100.0	372	364

Table 1 Vezzoli et al.